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EXPLORATION AND DEVELOPMENT OF SMALL MINES

BY H. E. KRUMLAUF

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EXPLORATION AND DEVELOPMENT OF SMALL MINES

By H. E. Krumlauf*

INTRODUCTION

The information given in the following discussion is for small mine operators and those who might become interested in small mines. Seldom will the cost figures, as shown, fit exactly a given mine; they are presented here to help the potential operator make reasonable estimates of the capital needs and operating expenses involved in exploration and development of small mines.

PART I — PREPARATION AND COSTS

PRIMARY APPRAISAL

Assume that the prospector has found a promising outcrop, mineralized zone, or geological structure, indicating the possibility of an ore deposit, and that he has properly located and recorded a claim or claims to cover the area. The prospector then should sample the outcrop or zone by taking samples from trenches or test pits that have been dug into the solid rock of the outcrop or zone of mineralization.

If the samples show that ore has been found, a development program can be planned, and, if capital is available, this plan can be put into operation. At this point many prospectors make a serious error by believing that the material found is ore. The United States Geological Survey defines ore as follows: "Ore is a natural aggregation of one or more minerals from which useful metals may be *profitably extracted.*" It requires considerable mining and metallurgical experience to determine if the valuable minerals found can be "profitably extracted" and to determine if the material found is actually "ore."

At this point the wise prospector will obtain the services of a competent consulting mining engineer either to direct the operation or advise him on the best procedure for his property. Such an engineer should be well and favorably known in his profession and registered in the State where he practices. The cost of obtaining the services of a competent consultant is about $100 per day and expenses if employed on a short-term daily rate or, if the consultant is to plan and direct the operations during the development stage, he would be paid a monthly salary of about $500, more or less, depending upon the amount of work involved. These costs are given only as a general guide to the prospector and may vary from one district to another.

If the sampling results are encouraging, although indicating material too low in grade for "ore" as previously defined, or if the prospector believes that he has found a promising geological structure, he then should obtain the advice of a competent mining geologist. This man should be well and favorably known in his field. Such a geologist probably would be employed only on a short-term basis, and his services will cost about $100 per day

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plus expenses. The cost of the geological examination is money well spent, and the prospector would do well to follow the geologist's advice. The charges made by consulting geologists may vary considerably.

The cost of obtaining professional services may seem to be high, but in most cases the advice given the operator will save many times the cost of this service.

SURFACE EXPLORATION

General Program

The report that has been submitted by the consulting geologist will recommend one of several courses which generally may be summarized as follows:

1. Abandon the property for lack of sufficient evidence to warrant the cost of additional exploration. The prospector should follow this advice.
2. Additional trenching and test pitting along the outcrop to determine the extent of mineralization, or for additional information on the structure.
3. Drilling to determine values or geological structure at depth.

Trench Sampling: Trenching can be done with pick and shovel to depths of 6 or 7 feet and 2 to 3 feet in width, depending upon the depth. Its cost will depend to a considerable extent upon the type of material in which the trench is dug. In soil with some rocks but no large boulders, the average cost is $3 to $4 per cubic yard of material removed.

For large amounts of trenching, a bulldozer should be used. This machine also will handle rocky soil at a much lower cost than may be achieved by pick and shovel. The cost per foot of trench may be about the same for each method, but the job can be done in a much shorter time with a bulldozer. Also the wide blade on the dozer will expose more of the bedrock for examination. A bulldozer of sufficient power to handle the job will cost $75 to $100 per day or $300 to $350 per week of 6 days, including operator, service, fuel, and repairs. In addition to this amount is the cost of trucking the equipment to the prospect and return, which should not exceed $25.

Pit Sampling: Test pitting is necessary where overburden is too thick for trenching. Test pitting is similar to the sinking of a discovery shaft. Test pits are usually 4 by 4 ft. or 4 by 5 ft. in cross section and may be 30 to 40 ft. deep. Test pits down to 10 feet deep in soil or gravel will cost from $5 to $7 per foot without timbering, but the cost per foot will increase with depth and amount of timber necessary. These costs are for dry ground.

Diamond Drilling: If the consulting geologist recommends a diamond drilling program, he should determine the location for each hole together with its direction, angle, and depth. The initial drilling program for the prospect rarely exceeds a total of 1,000 feet of hole, which is considered by the driller as a small

contract. Since the condition of the rock to be drilled is unknown, and the amount of drilling is small, the contract price for the job may range from $4 to $6 per foot, with possible extra charges for cementing holes where necessary and for casing if needed.

Under certain circumstances it may be better for the claim owner to pay for drilling on a "cost plus" basis. With a contract of this type, the claim owner pays the drilling costs plus an additional amount per foot. This additional amount may range from 75 cents to $1 per foot. The claim owner should determine in advance just what items will be included in the cost.

Wagon Drilling: In areas where the mineral bodies are of considerable horizontal extent and at shallow depths, a wagon drill may be used successfully for exploration. This type of rig includes a standard wagon drill equipped with a 4-inch air-driven drilling machine and a compressor of 315 c.f.m. (cubic feet per minute) capacity. Drill rods 1¼ inches to 1½ inches in diameter with ¼-inch hole in the center, and a 2½-inch to 3-inch tungsten-carbide bit, are employed. Drilling is done without water; air, forced down through the hollow rods, brings up the cuttings and cools the bit. A 4-inch collar with side outlet is placed over the hole. The collar has a bushing at the top through which the drill rods pass, and the air and cuttings flow through the side outlet to a dust collector, which may be of simple cone design.

This type of drilling is particularly suited to shallow deposits where the depth does not exceed 100 to 125 feet. However, under very favorable conditions, holes as much as 200 feet deep may be drilled. The rock must be dry.

For a drilling program of approximately 2,000 feet, the cost per foot should be less than $2. With greater total footage, the cost can be reduced; if 20,000 feet, it may be as low as $1 per foot.

Ore Values for Small Mines: At this point in an exploration program, the operator must appraise carefully the information obtained. If drilling has shown that no valuable minerals are likely to be found, the claims should be abandoned. Only if the results indicate ore, may he plan the next step in exploration.

Type of ore	Grade of per ton	Value per lb. or oz.	Gross Value	Ore buyers* return (approx.)
Copper	5½%	25c/lb.	$27.50	$14
Lead	15 %	12½c/lb.	37.50	14
Zinc†	25 %	10c/lb.	50.00	14
Gold (flux)	0.6 oz.	$35/oz.	21.50	14
Silver (flux)	24 oz.	90.5c/oz.	21.75	14
Uranium oxide (U_3O_8)	0.20%	$3.50/lb.	14.00‡	14

*Includes railroad freight to smelter or ore buyer.
†Zinc ore can be sold only to a custom mill, and at a market price of 10c per pound is of little value to the small mine operator. No payment for zinc is received from a copper smelter or lead smelter if some zinc is included in a lead, copper, gold, or silver ore.
‡Does not include development or haulage allowances and production bonus.

The table above gives a rough estimation of the "break even" grade of material for small mines. If the exploration indicates material of better grade for any single metal than is shown in the table, the mine might be profitable.

Complex ores containing combinations of the aforementioned metals may be sent to a custom mill or smelter. For example, an ore containing 12 per cent lead and 3 per cent copper, with a gross value of $45 per ton, can be shipped to a lead smelter, where payment for copper at a reduced price, combined with the payment for lead, will return a total of about $14 per ton to the shipper.

The "break even" grade of ore for the small mine operator, as shown in the above table, must return $10 per ton to cover direct mining costs; $1.40 for royalty at 10 per cent of the smelter or ore buyer's return; approximately $1.50 for trucking from mine to railroad; and a balance of $1.10 out of the total of $14 may be used for such items as taxes, insurance, exploration, legal costs, and surveying.

Under very favorable conditions, a small mine operator may be able to produce and ship ore for less than $14 per ton, whereas the cost for other operations having less favorable conditions may exceed $14 per ton. The final cost figure will depend upon such items as width of vein, strength of the ore and wall rocks, cost of transportation, royalty, ability of the mine operator, type of labor, and cost of supplies. The values given above are for estimating only, and an ore buyer or smelter representative should be consulted for more detailed information.

If, however, the gross value of the material discovered by the exploration thus far is equal to or greater than shown in the table on page 7, after adjusting for changes in market value, the next step in the exploration program can be planned and executed.

UNDERGROUND EXPLORATION

Trenching, test-pitting, and drilling may indicate the presence of valuable ore; however the physical characteristics of the indicated ore and the wall rocks can not be determined by these methods of exploration. To obtain this additional information, it will be necessary to examine the ore and wall rocks and sample the ore at some distance below the outcrop.

General plans for the underground exploration may be outlined as follows:

1. Appraisal of the labor situation in the district where the prospect is located.
2. Estimation of the size and cost of the surface plant.
3. Shaft-sinking costs.
4. Drifting costs.
5. Estimating the size and cost of equipment necessary to do the work successfully.

Labor

Pay Scale: The following table is approximately the union pay scale effective in Arizona as of May, 1954.

Classification	Base pay per shift
Miner	$15.44
Mucker	13.88
Topman	14.24
Hoistman	15.44

Since small mines commonly are located distant from larger mines, the pay scale tends to be less. For the example to be discussed, the following pay scale will be used:

Classification	Base pay per shift
Foreman	$15
Miner	14
Mucker	12
Hoistman	14

The small-mine foreman should be in immediate charge of the workmen, and he also should be ready to do or help with any job from mining to hoisting. The small mine cannot afford a lazy foreman.

The amount of material to be hoisted per shift from a small mine will require only part of the hoistman's time. The balance of his time will be spent in tramming ore or waste to places of disposal, framing timber, sharpening picks and moils, operating the compressor, and doing other odd jobs as needed.

The miner and mucker will do the drilling, mucking, timbering, and track laying as the job progresses.

Labor Costs: The base pay shown in the foregoing table is only part of the cost of labor to the operator. Substantial amounts in the form of insurance and taxes must be added to the base pay, as follows:

1. Overtime: If the mine is operated for six days per week at eight hours per day a rate of 1½ times the base pay must be paid for the sixth day. This overtime is then distributed equally to each of the six days to obtain the so called "payroll wage." All insurance and taxes are computed from the payroll wage and not the base pay.

2. Old Age and Survivors' Insurance (O.A.S.I.) in its various forms is commonly called Social Security. The O.A.S.I. rate, as of January 1, 1954, was 2 per cent of the payroll wage. This is a Federal insurance.

3. Industrial Insurance required by the State of Arizona is in two parts.

a. Industrial accident insurance for mining is 8.30 per cent of the payroll wage.

b. Occupational disease insurance for mining is 0.58 per cent of the payroll wage.

4. Unemployment compensation tax is part State and part Federal. This tax is a percentage of the payroll wage of any workman and is paid after he has been employed for a period of twenty weeks. However, it is retroactive to the beginning of the employment period.

a. State unemployment compensation is 2.7 per cent of the payroll wage.
b. Federal unemployment compensation is 0.3 per cent of the payroll wage.
The State rate may be reduced after one or two years if the company furnishes steady employment to its employees.

5. *In addition* to the above taxes and insurance, an established company may be required to pay for shift differentials, vacations, holidays, group insurance, transportation, and other items.

Example: The total daily cost per miner for a six-day week is computed as follows:

Miner's base pay per shift		$14.00
Weekly overtime distribution = $14 x ½ x 1/6		1.17
Payroll wage per shift		$15.17
Payroll insurance and taxes:		
O.A.S.I. @2.0 per cent x 15.17 =	$0.30	
Industrial Accident Ins. @8.30 per cent x 15.17 =	1.26	
Occupational disease Ins. @0.58 per cent x 15.17 =	.09	
State unemployment tax @2.7 per cent x 15.17 =	.41	
Federal unemployment tax @0.3 per cent x 15.17 =	.05	
Total tax and insurance	$2.11	2.11
Total cost per shift to operator		$17.28

The actual cost to the operator for labor, including taxes and insurance, is as follows:

Classification	Base pay	Total cost per shift
Foreman	$15	$18.52
Miner	14	17.28
Mucker	12	14.81
Hoistman	14	17.28

Mine Surface Plant

The type and size of surface plant will vary somewhat. For example, if the headframe to be built is for sinking and exploring with a sinking bucket, it would cost less than one designed for sinking and inclined shaft with a skip. However, this latter type of headframe can be used more efficiently for production.

An ore bin may be included as part of the initial surface plant to handle ore that may be found during the exploration, or this ore could be stockpiled in some convenient place, and the ore bin might be built later. A bin to hold 15 tons of ore would cost about $600.

	Estimated Cost
Headframe, including the shaft collar	$700
Buildings:	
12 ft. x 35 ft. for hoist, changeroom, shop, and storage — frame construction @$3.00 per square foot of floor area	1,250
Compressor shed	150
Powder house and outhouse	200
Leveling ground, installing surface equipment, laying track, fitting pipe	200
Water tank (used) installed	100
Air receiver (used) installed	200
Total	$2,800

The above cost of $2,800 is for a semipermanent installation which can be used, with some additions, for production. A temporary plant could be installed at a lower cost but must be replaced if the mine produces. Also the cost of roads for access and other purposes must be added to the total.

Shaft Sinking

The next step in the exploration program is the sinking of an exploration shaft to examine the mineralized area at depth. This shaft should be put down in the ore body or mineralized zone wherever possible. A shaft outside the mineralized zone will furnish no information of value to the operator. In some places the topography may not permit the building of a surface plant near the outcrop or the sinking of a shaft in the vein. For example, a cliff or steep mountain side may require the surface plant and shaft to be located away from the outcrop. Also, a shaft should not be put down in the outcrop if it is in the bottom of a wash. Too frequently the inexperienced operator drives a long tunnel to intersect the vein at depth, only to find that it has been faulted or has pinched out. This information could have been obtained at a fraction of the cost, had he sunk a shaft on the vein. Wherever possible, all exploration work should be done in the vein or mineralized zone.

It is customary to sink the prospect shaft about 110 feet and establish the first level at about the 100-foot depth in the shaft. The lower 10 feet of shaft will be used as a sump and for loading a skip where one is used

Cost of Shaft Sinking: A satisfactory small mine shaft, whether vertical or inclined, is 6 feet by 9 feet in rock cross section. This shaft, when timbered with wall plates and lagged, can be divided into a hoisting compartment 4 ft. by 4 ft. in cross section and a manway 3 ft. by 4 ft. in cross section. Guides for a cage would be installed in a vertical shaft, and stringers rather than ties should be used in an inclined shaft to carry the rails. Stringers 4 in. by 6 in. or 6 in. by 6 in., fastened to the sills, will give a stronger support to the rails than ties and also will keep the track in alignment.

The labor distribution and costs are shown as follows:

Number	Classification	Cost per shift
1	Working foreman	$18.52
1	Miner	17.28
1	Mucker	14.81
1	Hoistman	17.28
	Labor cost per shift	$67.89

A detailed list of the cost of supplies, tools, possible repairs, pumping, compressed air, insurance, transportation, sampling, assaying, accounting, and management would vary so much for each operation that only an estimate can be made. However, the cost sheets of a large number of underground mines indicate that these costs range from 30 per cent to 50 per cent of the total cost of the operation. The higher figure should be applied for mines where considerable timber is required, and the lower value may be used for mining under very favorable conditions. This percentage is for direct costs only and does not include the cost or rental of equipment. Hence, for estimates of operations such as shaft sinking, drifting, and stoping, the total cost may be divided on the basis of 60 per cent for labor and 40 per cent for all other direct costs. There will be exceptions to this division of costs, and, if they can be anticipated, allowances should be made. For example, labor efficiency is reduced when water is encountered in a shaft, and if a shaft is to be sunk in solid, but wet, ground the cost of labor would be higher. Inexperienced labor also may cause an increase in the labor cost.

If the cost of labor as shown in the foregoing table amounts to 60 per cent of the total cost of shaft sinking, then the overall cost per shift will be $67.89 divided by 60 per cent or $113.15. The cost of supplies and other items at 40 per cent will be $45.26.

Assume the average advance per shift of the completed shaft for the crew of four is as follows:

Advance, feet per shift	Labor cost per foot	Supplies, etc. cost per foot	Total cost per foot
1	$67.89	$45.26	$113.15
2	33.95	22.62	56.58
3	22.63	15.09	37.72

Shaft sinking for uranium ore on the Colorado Plateau is generally in very favorable ground and to shallow depths; hence its cost per foot in some cases may be less than shown here. Deep shafts cost more per foot than shallow shafts.

Drifting

The usual size of drift for the small mine is 5 ft. wide by 7 ft. high, which will allow for a track with 18-inch gage, a ditch, and pipes for air, water, and ventilation. In bad ground the drift should be driven 6 ft. by 8 ft. in rock section to allow for timbers.

The labor distribution and costs are shown as follows:

Number of men	Classification	Cost per shift
1	Working foreman	$18.52
1	Miner	17.28
1 (or 2)	Mucker	14.81
1	Hoistman	17.28
	Labor cost per shift	$67.89
Supplies, etc. at 40 per cent of total cost		45.26
	Total cost per shift	$113.15

In reasonably good ground, the crew should advance 4 feet per shift, which would amount to drilling, breaking, mucking, and hoisting 10 to 12 tons of rock. In ground requiring timber, the advance per shift would be 3 feet or less. However, if two drifts are being advanced, an extra mucker can be used advantageously, as a mucking crew of two men can be working in one drift, while the miner, with the foreman's help if needed, can be drilling in the other drift.

Cost of Drifting: The cost of drifting, including the laying of track and pipe, under various conditions is shown in the following table:

Number of men	Kind of ground	Advance per shift (feet)	Approx. cost per foot
4	Requires timber	3	$37.75
4	No timber	4	28.30
5	No timber	5½	25.00

The amount of drifting needed to prove or disprove the value of the property will vary greatly. In some instances it will be necessary only to check diamond drilling results; in case of small but high-grade ore shoots, considerable drifting may be required to determine the amount of ore available. Unless a definite amount of drifting can be determined in the beginning of the underground exploration, about 300 feet tentatively may be planned.

As no information regarding grade and characteristics of the ore can be obtained from drifts in the footwall or hanging wall, the drifting should be done in or along the vein whenever possible.

Raising

Raising may be done to explore ore shoots for development of ore, or for ventilation. Long raises for development or ventilation may be 4 feet high by 7 feet wide. A line of stulls will be placed along the center line of the raise, and lagging will be nailed onto one side of the stulls, dividing the raise into two compartments of which one is to be used as an ore pass, the other will be a manway with ladders.

For some types of stope development, short raises about 4 feet by 4 feet in cross section will connect the drift with the bottom of the stope. These raises are 12 to 15 feet long.

Cost of Raising: Raising is usually done while other phases of mining are being carried on. Thus the cost per foot is materially reduced, since supervision and hoisting are available without much additional cost. Also, mucking is necessary only at the start, as a chute should be installed after the raise has been advanced 10 or 12 feet.

In good ground a two-man crew should advance a 4-foot by 7-foot raise 3 feet per day. This work should include all drilling, blasting, timbering, and tramming. The total cost per day would be about $54 or about $18 per foot. For long raises, over 75 or 100 feet, the cost will be higher. The 4 feet by 4 feet chute-raises will cost $10 to $12 per foot, not including cost of the chute.

Equipment

General List: The major equipment items for small mines may be either rented or purchased. During the exploration stage it is advisable to rent this equipment and thus materially reduce the initial capital outlay. Furthermore, equipment may be obtained on a rental-purchase agreement in which 75 per cent of the rent may be applied on the purchase price. This method permits a small mine operator to obtain equipment on a type of installment plan.

The following is a list of equipment that may be rented:

Item of Equipment	Cost used	Cost new	Rent per month
Compressors:			
105 c.f.m.—gasoline driven	$2,250	$3,400	$140
160 c.f.m.—gasoline driven	2,850	4,700	185
160 c.f.m.—diesel driven	3,500	6,000	235
210 c.f.m.—gasoline driven	3,750	5,900	260
210 c.f.m.—diesel driven	4,500	7,300	298
Hoist:			
For cage with 4,000-to 4,500-pound rope pull (gasoline)	2,600	4,000	150
For skip with 2,000-to 2,500-pound rope pull (gasoline)	1,500	2,300	100
For bucket with 1,000-to 1,200-pound rope pull (gasoline)	1,000	1,600	60
Air drills:			
45-pound air leg drill, complete	400	585	60
55-pound air leg drill, complete	450	605	60
2⅝ inch stoper	375	735	65

The used equipment listed in the above table must be of a late model and in good reliable condition.

The following is a list of equipment that must be purchased:

Item	Estimated cost
3 mine cars (used) 16 to 18 cu. ft. capacity at $100 each	$ 300
1 truck—1 ton (used)	1,500
1 pump (used)—small air driven duplex	75
1 mine fan—gasoline engine driven (used)	250
Auxiliary hoisting equipment—skip, sheave, rope	300
Total	$2,425

The prices listed are for good used equipment and may vary somewhat in different localities. New equipment would cost about twice the amount shown.

Supplies to be Purchased: Supplies, such as powder, fuse, detonators, bits, drill rods, and timber, that are consumed during the operations, have been included in the cost of shaft sinking, drifting, and raising, as shown in preceding computations. The following supplies listed are part of the capital expenditures and have not been included in the previous costs:

Item	Estimated cost
Track:	
16-lb. rails for an inclined shaft About one ton (used); not needed for vertical shaft.	$ 120
12-lb. rails for surface and underground About 2 tons (used).	240
Spikes, bolts, fish plates, and ties estimated at	150
Pipe:	
500 feet of 2-inch, black iron, @40c per foot (new) for compressed air line	200
500 feet of ¾-inch, galvanized, @16c per foot (new) for water pipe	80
Miscellaneous pipe fittings estimated at	100
Ventilation:	
450 feet of 10-inch galvanized pipe @1.00 per foot	450
Ventilation pipe fittings	50
Hose:	
2 50-foot lengths of 1-inch air hose with fittings @$40.00 each	80
2 50-foot lengths of ½-inch water hose with fittings @$25.00 each	50
2 line oilers for drilling machines @$22.00 each	44
General tools:	
Picks, shovels, saws, axes, wrenches, anvil, forge, and other tools estimated at	500
Total	$2,064

Rent: Rent paid during the exploration period is part of the capital investment. If the equipment is obtained on a rental-purchase contract, and if the exploration is successful, only a portion of the rent is chargeable directly to the exploration.

Since, however, the mine operator must provide for payment of the rent during this period, it is usually more convenient for estimating purposes to include all the rent in the exploration costs.

The time required to complete the exploration outlined is as follows:

Shaft sinking at 2 feet per day will require fifty-five days to complete 110 feet of shaft.

Drifting at 4 feet per day will require seventy-five days to complete 300 feet of drift.

Allowing twenty-four shifts per month and a few shifts for a safety factor, six months would be required to complete the exploration. Therefore the rental costs would be as follows:

Item of Equipment	Rent per month	Total cost for six months
*105 c.f.m. compressor (gasoline)	$140	$ 840
Hoist for skip	100	600
†2 air-leg drills	120	720
		$2,160

*If compressed air is to be used to operate equipment other than drills, a larger compressor should be provided.

†A spare drilling machine is necessary.

Summary of Costs:

Item	Estimated cost
Surface plant	$2,800
Shaft sinking 110 feet at $56.58 per foot	6,200
Drifting 300 feet at $28.30 per foot	8,490
Equipment to be purchased	2,425
Supplies to be purchased	2,064
Rent	2,160
	24,139
Allow for miscellaneous cost, such as sampling and assaying	1,000
	$25,139

Under good supervision and favorable conditions, the total cost may be reduced as much as 25 per cent. However, under poor supervision or adverse conditions, the cost will be substantially higher.

The cost figures shown here are only to guide the small mine operator or the investor in small mine exploration. No two explorations are exactly alike, and no two operators have identical costs; therefore the above cost figures, although derived in part from actual small mine operations, will correspond to a given exploration only by chance.

PART II — MINING METHODS FOR SMALL MINES

FACTORS GOVERNING CHOICE OF METHOD

General Statement

From information obtained during the exploration program, a mining method may be selected for removal of the ore. If, however, the exploration consisted only of drilling and test pitting, a method cannot be selected until a shaft has been put down, or adit driven, and enough drifting and cross-cutting has been done to determine the physical characteristics of the ore and wall docks. This mining method should be the most suitable as well as the most economical one that will fit the conditions found.

Of the many factors or conditions that may influence choice of a mining method, the more important are listed as follows:

1. Strength or physical characteristics of the ore and wall rocks.
2. Value of the ore.
3. Dip, length, and width of the ore body.
4. Amount of capital available.
5. Experience.

The above conditions are not necessarily listed in their order of importance, since under certain circumstances some other condition may be of greater importance. For example, a mining method that requires a considerable amount of timber may not be the most economical, if timber must be transported great distances at a very high cost.

Strength or Physical Characteristics: The strength or physical characteristics of the ore and wall rock, such as texture, hardness, jointing, and faulting, indicate the ability of the ground to stand unsupported over a given span. This unsupported span is generally the principal factor that indicates the most suitable mining method to be used for a given ore body.

Value of the Ore: High-grade ores should be mined by a method that permits a high percentage of ore recovery. Such methods tend to be relatively expensive, but the value of the additional ore recovered should more than pay for the additional cost. Conversely, low-grade ores must be mined by low-cost methods, even though the percentage of recovered ore is lower.

Dip: The ore from flat-dipping veins must be removed by mechanical or hand means, whereas ore from steeply dipping veins will move to the haulage levels by force of gravity. Certain mining methods do not lend themselves to successful operations on flat dips.

Length of ore body: A regular method of support can be designed for ore bodies of substantial length, but those shorter than 50 feet may not require regular support, or they may be mined by "gophering." In the case of the small ore body, no regular method of mining is used

Width of ore body: An ore body of 10 or more feet wide may be mined by one of several methods, the choice of which may depend upon some condition other than width. For removing the ore from a vein 5 feet wide, only two methods are available, and one of them depends primarily upon a physical characteristic of the ore or wall rock rather than upon width.

Capital available: If the amount of capital available is small, only those mining methods that require a small amount of development work may be considered. Sub-level stoping is a very low-cost method of mining, but it requires a substantial amount of capital for development. Hence, a small amount of capital will prevent use of this method and necessitates a less economical method.

Experience: There is no substitute for mining experience. It is improbable that a person with little or no mining experience could select a suitable mining method or develop a mine for production. Inexperienced people generally mine by "gophering" or "gouging," and unless the ore is high grade, the operation is apt to fail.

Each mining method described in the following discussion has been devised to fit a particular set of conditions and when properly used should be the most economical and safe method for those conditions. In some instances there will be a choice of one or more methods, but the final selection should be based upon economical production with safety.

As used in this discussion, a "strong" ore or wall rock in general is one that will stand unsupported over a width of at least 10 or 15 feet and a length of 100 feet; a "weak" ore or wall rock is one that will not stand unsupported over an area of approximately 6 feet by 6 feet for more than a short period of time. Some ores and wall rocks belong between these two extremes, but methods have been devised for the mining of ore under almost any set of conditions.

PARTICULAR METHOD

Gophering or Gouging

Some ores are mined without any regular procedure or support. Such a method, if the term "method" can be applied, is used to mine irregular stringers or shoots of ore. In many cases, however, its use results from inexperience. This method, if applied to a larger and more uniform ore body, would soon render the mine area dangerous for workmen to enter, and the remaining ore might be lost. Since gophering or gouging has only a very limited application, it will not be discussed further.

Starting The Stope

When the physical characteristics of the ore and wall rocks are known, and a mining method has been chosen, it will be necessary to prepare the ore body for mining. Raises should be driven at each end of the planned stope, if the ore shoot is more

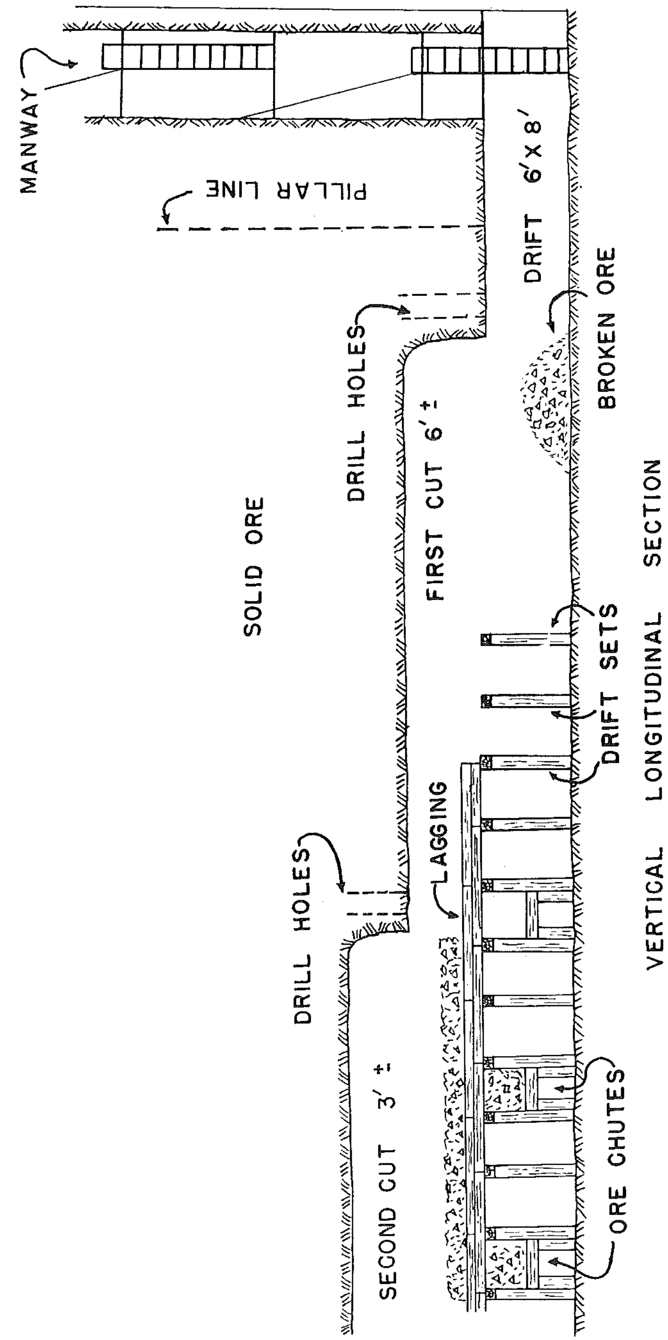

Figure 1.—Starting the stope on drift sets.

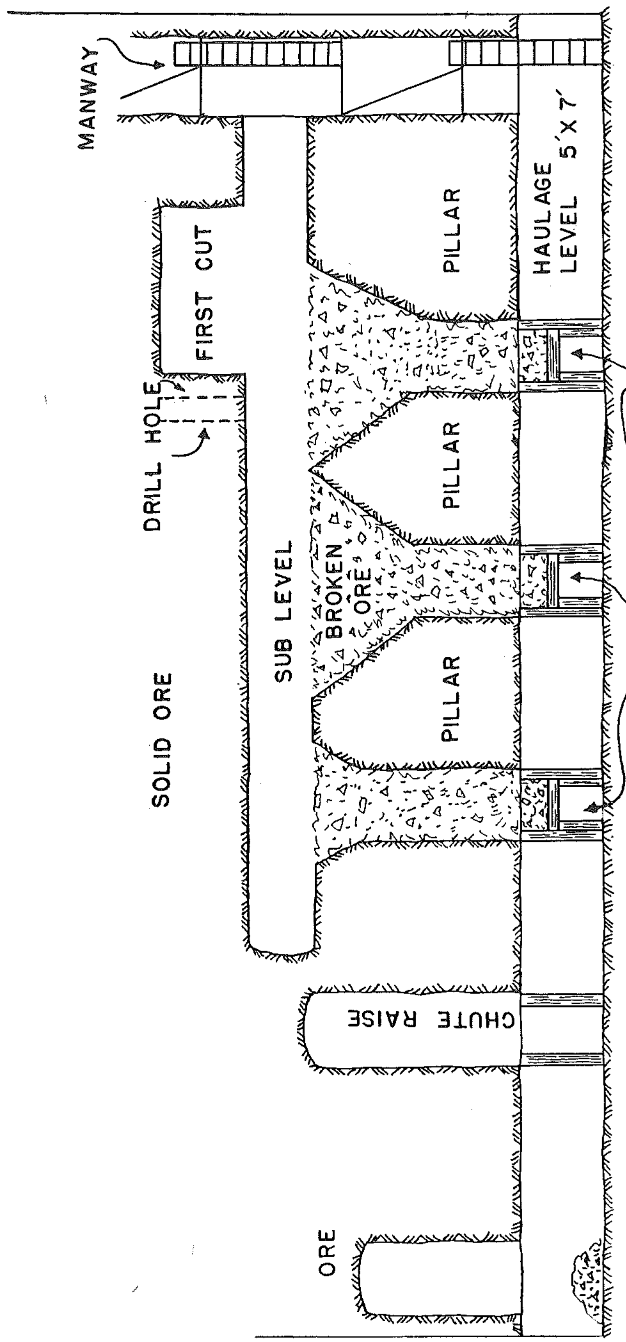

Figure 2.—Starting the stope on drift pillars.

than 50 to 75 feet long; otherwise only one raise may be used, and it should be at one end of the stope. Raises are to be used for ventilation and to permit access to the stope. If adequate mechanical ventilation is available, the raises can be driven as the stope is advanced; otherwise they should be driven before the stope is started.

Stoping may be started directly on drift sets as shown in Figure 1, or above drift pillars as shown in Figure 2. Each of these methods has certain advantages and disadvantages as given in subsequent paragraphs.

Stoping on drift sets: (Fig. 1)

Advantages: 1. Full production can be attained almost immediately.

2. No chute raises necessary for shrinkage stoping.
3. No ore lost in drift pillars.
4. Best for level intervals of 75 feet or less.

Disadvantages: 1. Cost of drift sets.

2. Where dip is 60 degrees or more, the weight of broken ore or waste may crush the drift sets.
3. Not recommended for veins over 10 feet thick.
4. Timbered drift must be kept in repair.

The stope is opened by first taking a cut about 6 feet high out of the back of the drift, from foot to hanging. This ore is removed, and regular 3-piece drift sets are put in at about 5-foot intervals. The drift sets are lagged on the sides and double lagged on top. Chutes are built into the drift sets at about 15-foot intervals, if the shrinkage stoping method is to be used. When the drift is completely timbered, a second cut is taken from the back. This second cut should not be more than 2 or 3 feet thick and should be blasted lightly to prevent breaking the lagging on top of the sets. This ore is left on top of the timber to act as a cushion, if the shrinkage method is used; or the ore is removed, and waste filling is put in its place, if the cut-and-fill method is used. The stope is then carried upward either on broken ore as shown in Figure 7 or on waste fill as shown in Figure 4.

Starting the stope on drift pillars: (Fig. 2)

Advantages: 1. Better protection for the drift.

2. Best for level intervals over 75 feet.
3. Very little costly timber used.
4. No repair work on timber.
5. Not limited by the dip of the vein.

Disadvantages: 1. Requires more development work for full production.

2. Chute raises necessary for shrinkage stoping.
3. Some ore may be lost in drift pillars.

Opening the stope on drift pillars is probably the safest and most satisfactory method to use. If mining or exploration is to be done beyond the stoped area, the drift will remain open. In the long run, the cost will probably be lower with drift pillars. The stope is opened by driving a small drift parallel to the main drift and from 10 to 25 feet above it. This sub-drift is driven from the raise on one end of the stope to the raise on the other end.

In the shrinkage stoping method (Fig. 7), chute raises at intervals of about 15 feet are driven from the haulage drift to the sub-drift, and their tops are funneled out to cut the vein off from foot-to-hanging wall for the full length of the stope.

In the cut-and-fill method, the stope is started from the sub-drift, and the broken ore is trammed or scraped to the nearest ore pass. The fill then is placed directly on top of the drift pillar.

Room-and-Pillar Method

The room-and-pillar method is used extensively for mining of flat-lying deposits or for veins or beds of ore which dip less than 35 or 40 degrees from the horizontal. It is a very simple method of mining. (Fig. 3)

The width of the rooms (stopes) and the size of the supporting pillars depend upon the strength of the wall rocks, especially the hanging wall, the strength of the ore, and the distance below the surface. **Pillars 8 to 10 feet thick with rooms 15 to 20** feet wide are common in metal mining. With strong ore and a strong hanging wall, 10-foot pillars and 30-to 35-foot rooms are possible. With a weak hanging wall, 15- to 20-foot rooms may be possible if two rows of stulls are placed in the stope, parallel to the pillars, for added support of the hanging wall. Openings are made through the pillars where needed to permit better ventilation of the rooms.

The first mining, that is, the removal of ore from the drifts and rooms, will give a 60 to 70 per cent extraction of the ore, and the balance remains in the pillars. When a section of the ore above one drift has been mined, the pillars can be robbed (mined). It is usually impossible to remove all the ore from the pillars, but in most cases enough can be removed to give an over-all extraction up to 90 per cent.

In horizontal or nearly horizontal deposits, the mine cars can be loaded at the face of the room. For dips exceeding 5 or 10 degrees, either scrapers or conveyors are used to move the ore to cars in the haulage drift. For dips of more than 20 degrees, the scraper is most commonly used.

Advantages of the method: 1. A simple method of mining.
2. Well suited to veins or bedded deposits which dip less than 40 degrees.
3. Full production possible in a short time.
4. Small amount of capital tied up in development.
5. Small amount of timber necessary in most cases.

Disadvantages: 1. Cannot be used on steeply dipping deposits.
2. Considerable ore left in pillars to be robbed later.
3. Additional equipment as scraper hoists and scrapers needed.

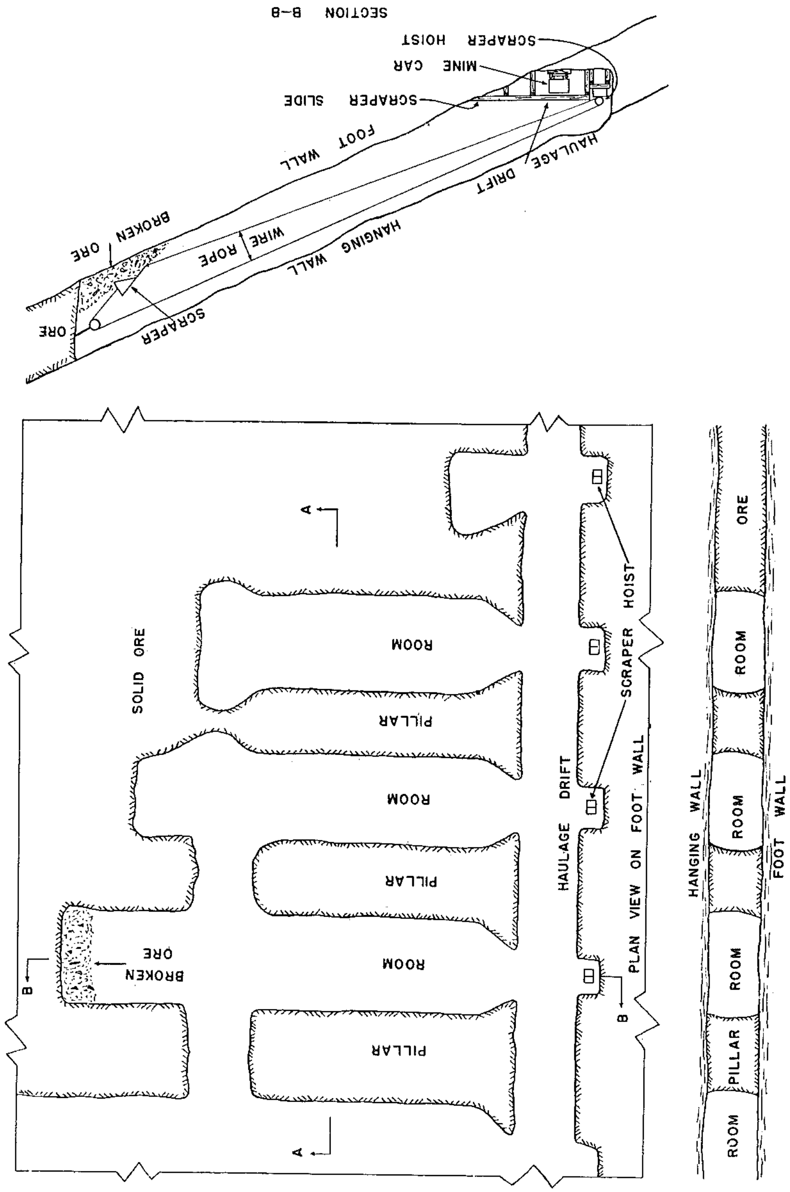

Figure 3.—Room-and-pillar stoping.

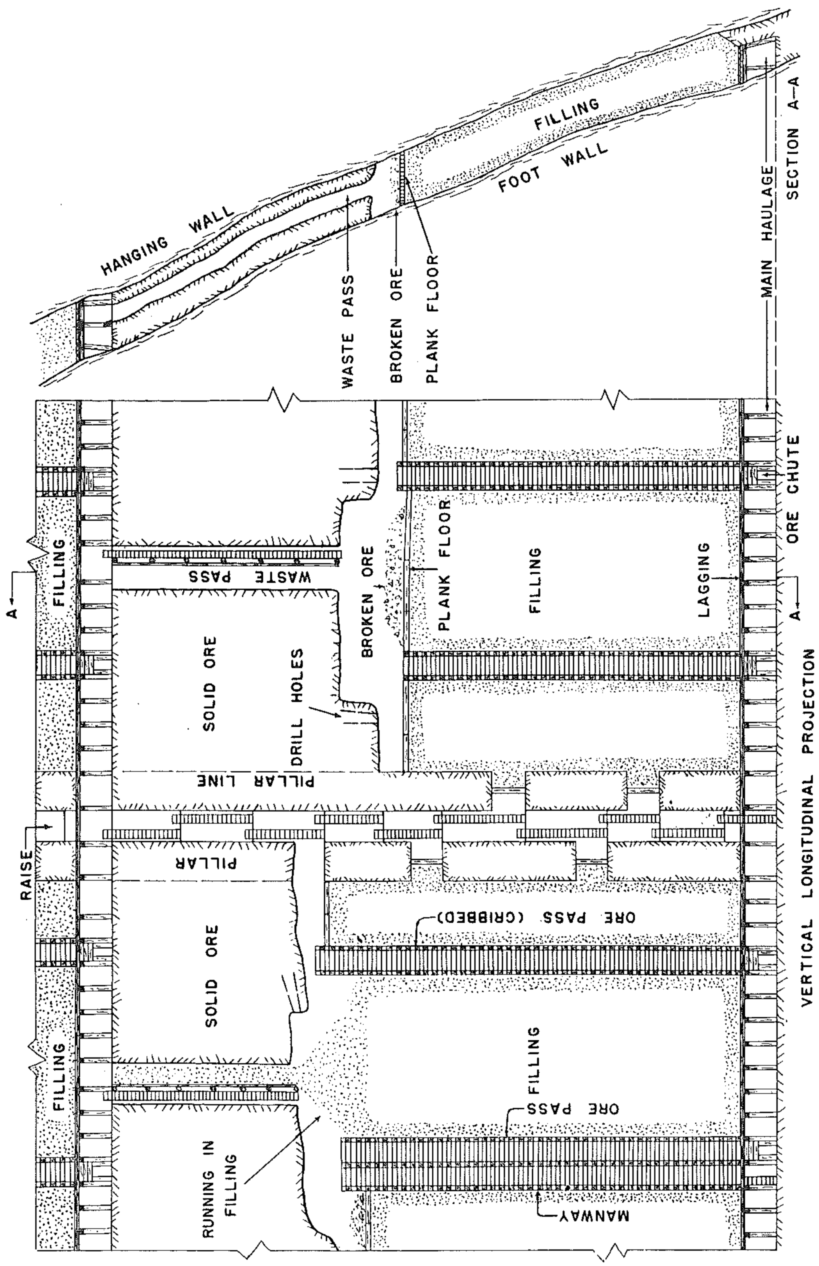

Figure 4.—Horizontal cut-and-fill stoping on drift sets. (After U.S. Bur. Mines Bull. 419, *Metal-Mining Practice*, by C. F. Jackson and J. H. Hedges).

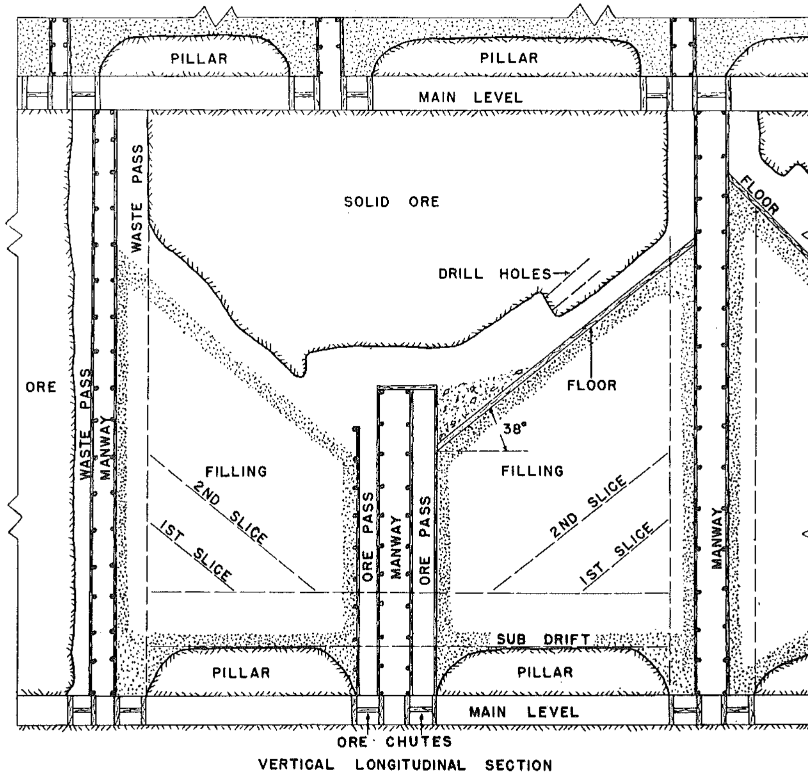

Figure 5.—Inclined cut-and-fill stoping on drift pillars. (After U.S. Bur. Mines Bull. 419).

Accident record: Fairly low for deposits less than 8 feet thick, but the rate is higher for thick deposits.

Cost per ton: For small mines the cost should be from \$5 to \$10 per ton, except for very thin deposits.

Cut-and-Fill Stoping

In the cut-and-fill method, a 4- to 6-foot cut of ore, from foot to hanging wall and the length of the stope or panel, is blasted from the back of the stope and transferred to the haulage level. A volume of waste material is then brought into the stope to fill a space equal to the volume of ore removed. It is from this procedure that the name "Cut-and-Fill" was derived.

The method is divided into two types, although the general procedure is about the same for both. The principal type is called "Horizontal" or "Flat Back" cut-and-fill stoping because the mining faces in the stopes are horizontal or nearly so, as shown in Figure 4. The other type is called "Inclined" or "Rill" cut-and-fill stoping, because the mining face is inclined at an angle that will cause the broken ore to flow to the ore pass by force of gravity, and the waste filling will flow into the stope from the waste raises as shown in Figure 5.

By this method, stoping may be done on drift sets as shown in Figure 4 and 1, or on drift pillars as shown in Figure 5. The choice will depend upon the width and dip of the ore body as explained before, the cost of timber, and the experience of the operator.

The method is used in ore bodies where the ore is strong and will stand unsupported over the width of the ore body and the length of the stope. One or both walls may be weak and require support. The supporting material is waste rock that has been obtained from development work in the mine or from some source outside the mine.

This method may be used in either narrow or wide ore bodies which dip at least 40 degrees or steeper.

Advantages: a. Caving is reduced by the filling.
b. Irregular extensions of ore can be mined.
c. Waste can be sorted from ore in the stope.
d. Ore is removed from the stope soon after it has been mined.
e. Oxidation of the ore is reduced to a minimum.
f. Large pieces of ore can be broken in the stope.
g. Horses of waste can be left in place.
h. Less dilution of ore with waste.
i. Stope can be well ventilated.

Disadvantages: a. High cost of mining.
b. Low production per man-shift.
c. Difficulty in obtaining filling.
d. Mining is stopped while fill is being placed.
e. Fill must be covered by flooring.
f. Some loss of fines through flooring.
g. Considerable amount of timber used.
h. Timbered raises through the filling get out of line due to settlement of filling.

Safety Features: The accident rate is fairly low.

Cost: The cost per ton for small mines may be from $10 to $15.

The inclined or "Rill" stoping method should be less costly than the horizontal or "flat back" method, but the accident rate is much higher. Rocks rolling down the inclined flooring or filling cause many injuries, especially in narrow and steeply dipping veins.

Stull Stoping in Narrow Veins

A stull is a single piece of timber that is set between the foot and hanging wall of the vein as shown in Figure 6. If the timber is vertical or nearly vertical, it is usually called a post rather than a stull. As shown in Figure 6, a great many stulls are used in this method, which gives rise to the name, "Stull Stoping."

The stull stoping method is used in veins 6 feet thick or less,

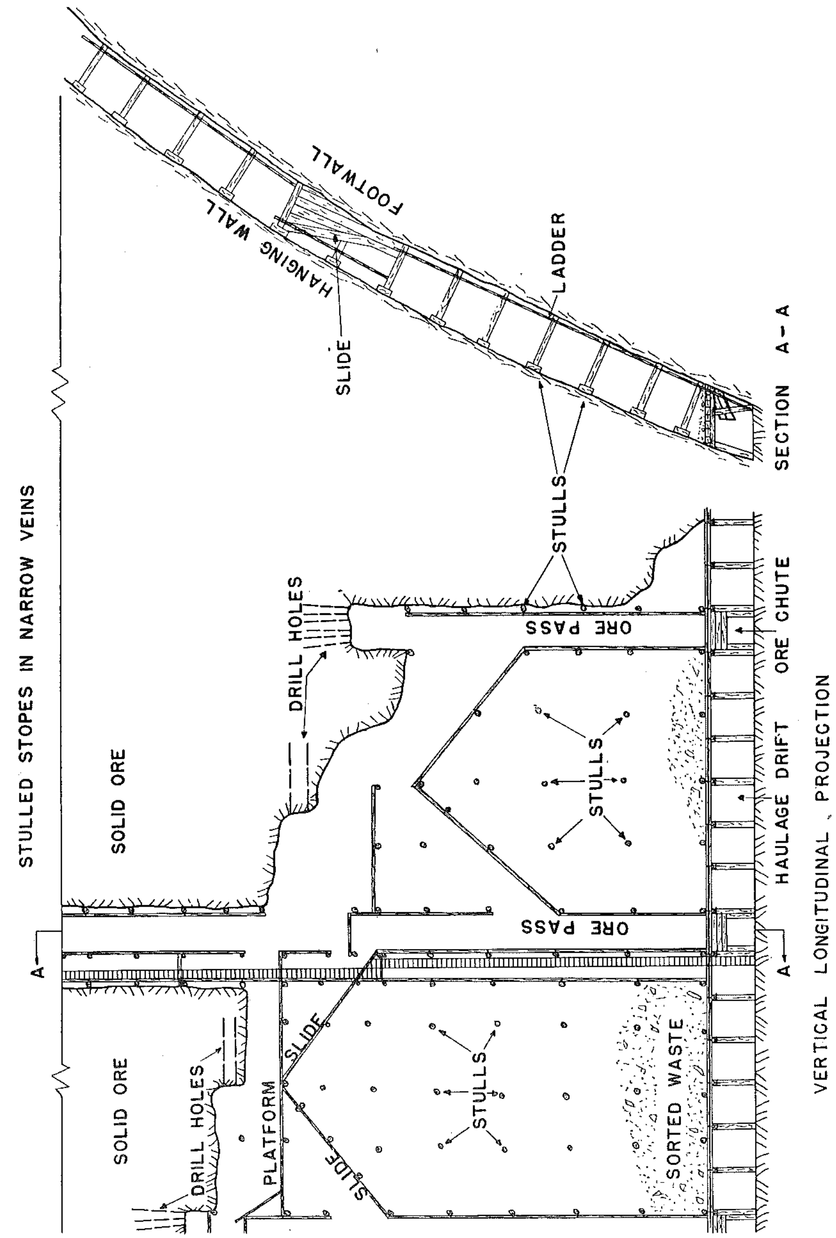

Figure 6.—Stull stoping in narrow veins.
(From U.S. Bur. Mines Bull. 419).

where the ore is strong and the wall rocks are strong or fairly strong. The dip of the ore body should be 40 degrees or more so that the ore will move along the slides and ore passes by the force of gravity. It can be used on flatter veins, but the ore must then be moved to the main haulage levels by mechanical means or wheelbarrows.

Advantages: a. Small amount of capital is required to bring the mine into production.
b. Mine can be brought into production in a very short time.
c. Ore can be sorted in the stope if necessary.
d. Miners' work under low, solid back that can be examined easily for loose rock.
e. Good ventilation is possible.
f. It is a simple method of mining.

Disadvantages: a. Production per man shift is low because the vein is narrow, and because of the time used in setting timbers and building slides and platforms.
b. A large amount of timber is necessary.
c. Dangerous to work on platforms.
d. Valuable fine ore may be lost through the platforms and slides.

Safety features: The accident rate is fairly high because of the danger of falling from platforms.

Cost: The cost varies with the thickness and hardness of the ore but should be between $7 and $12 per ton.

Shrinkage Stoping

In this method about two-thirds of the broken ore is left in the stope to act as a platform from which the miners can drill above. One-third of the ore is removed either through chutes at the bottom of the stope or by scraping to raises at the ends of the stope. This one-third must be removed, since broken ore occupies about one-third more space than solid ore.

The stope may be started on drift sets as shown in Figures 7 and 1, or on drift pillars as shown in Figure 2. Wide stopes are usually started on drift pillars, because the weight of broken ore in the stope may be greater than drift sets could hold. However, narrow ore bodies, less than 8 feet or so in width, may be safely started on drift sets.

Vertical holes, drilled with a stoper, generally are used to break the ore. In some places, however, the vertical holes tend to shatter the back and make the stope unsafe; under these circumstances air-leg drills are used to drill horizontal or nearly horizontal holes. Both methods are shown in Figure 7.

If the broken ore is removed through chutes placed at the bottom of the stope, the trammers should check with the miners to see that the top of the broken ore moves down evenly while being drawn. If the vein is narrow, less than 5 or 6 feet, or if the walls of the stope are irregular, the broken ore may arch

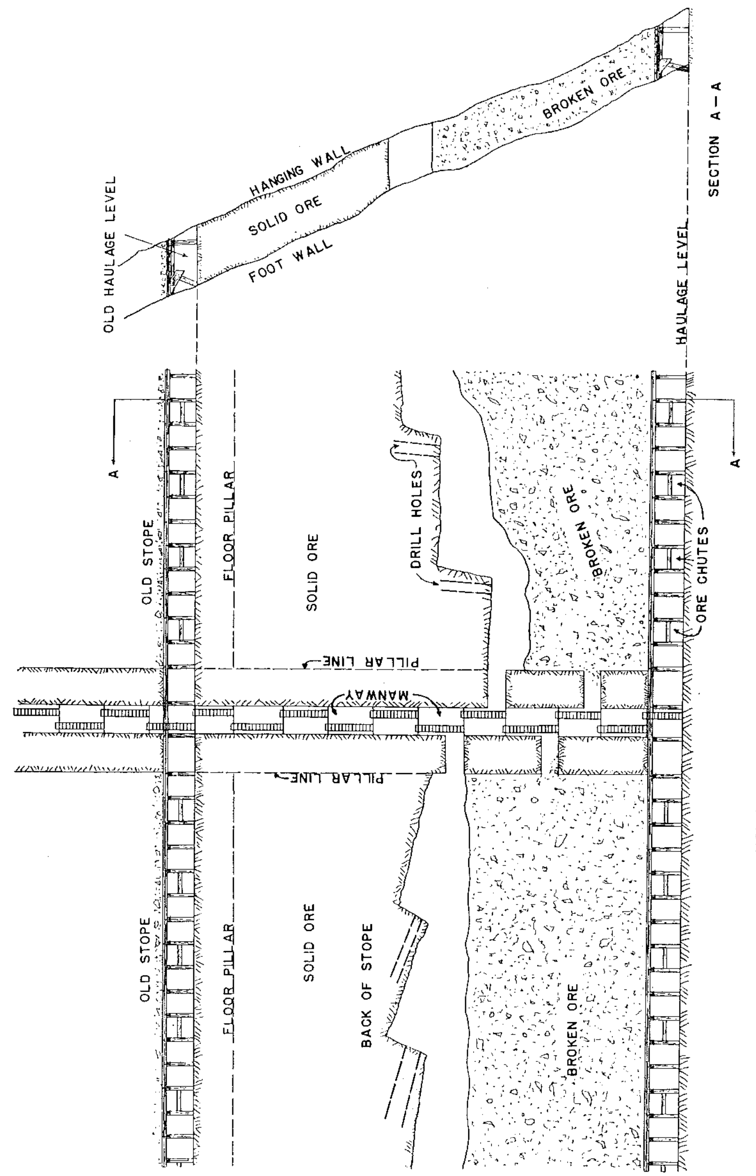

Figure 7.—Shrinkage stoping on drift sets.
(After U.S. Bur. Mines Bull. 419).

across from foot-to-hanging wall, forming an open pocket between the top of the broken ore and the chutes. The vibration caused by a drilling machine may break this arch; the miner may be drawn into the pocket and covered with broken ore. Accidents of this type are usually fatal.

In ore bodies that are narrow or have irregular walls the broken ore should be removed by scraping to raises at the ends of the stope. This change in the method requires more equipment but removes a safety hazard.

The method may be used where the ore is strong, and where the wall rocks will not slab off and dilute the ore. Also the dip must be sufficiently steep, 45 degrees or more, to cause the ore to slide down the footwall.

Advantages: 1. Low cost of mining.
2. Some production can be obtained immediately.
3. Small amount of capital in development work.
4. Large number of men can work in a small area.
5. High production per man-shift.
6. Broken ore gives some support to wall rocks.
7. Large chunks of ore can be broken in the stope.
8. Small amount of timber used.
9. Very common method of mining.
10. Experienced workers are usually available.
11. Good ventilation of stopes is possible.

Disadvantages: 1. Two-thirds of ore remains in stope until completed.
2. Considerable capital tied up in broken ore.
3. Possible dilution by wall rock.
4. No sorting of waste from ore in stopes.
5. Arching of broken ore is dangerous.
6. Ores with 25 per cent or more of sulphides may burn.
7. Oxidation of broken ore may reduce mill recovery.

Safety features: Accident rate is fairly high because:
a. Method is sometimes used in unsuitable ground.
b. Careless drawing of ore by trammers.
c. Poor supervision.

Cost per ton: The cost will vary from \$6 to \$12, depending upon width of the ore.

Square-Set Stoping

As the ore is removed from the vein in the square-set method of mining it is replaced by a framework of timbers. These timbers offer temporary support to the ground and when the mining has advanced far enough the framework is filled with waste. This framework consists of rectangular box-like sections called square sets consisting of four posts, two caps and two girts. Each timber is framed to fit into its proper place, and each set will fit into the adjacent set or sets. See Figure 8.

The method is used where the ore or the ore and wall rocks are heavy and will stand unsupported over only very small

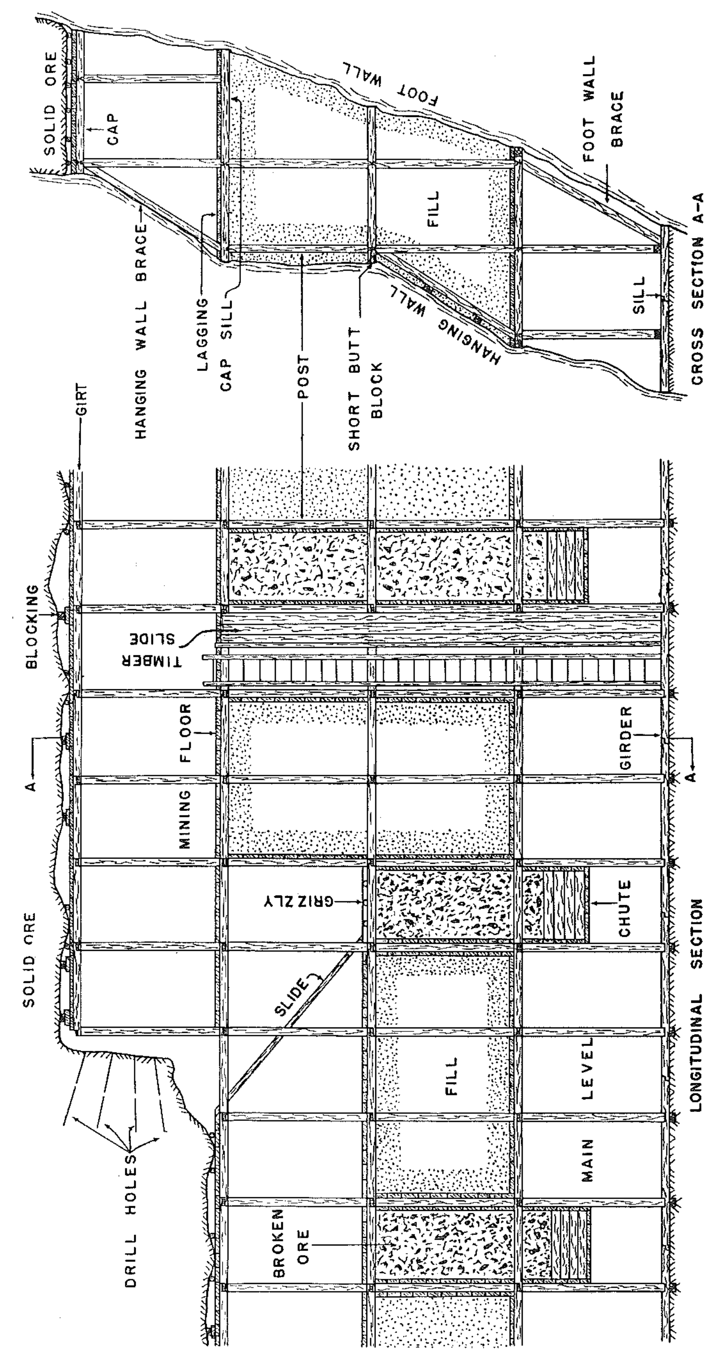

Figure 8.—Square-set stoping in narrow veins. (After U.S. Bur. Mines, Inf. Cir. 6691).

areas, usually not much over 6 by 6 feet or so. A section of ore the size of a square set is removed and a set is placed in the opening, lagged and blocked into place. The method is very flexible as the sets can be extended in any direction or can be left out while mining around a block (horse) of waste or in mining a narrow part of the vein. Sets may also be added to the regular sets, so that stringers of ore extending into the foot or hanging wall may be mined.

It is a very high-cost method of mining and can not be used for the mining of low grade ore bodies. This method should be adopted only after all other methods have been considered or tried. It is possible to obtain 100 per cent extraction of the ore with this method and hence it is sometimes used for the mining of high grade ore bodies that could be mined by cheaper methods; because the high percentage of ore recovered will more than pay for the high cost of mining.

Advantages of the method: 1. Irregular ore bodies can be mined.
2. Horses of waste can be left in place.
3. Waste may be sorted from the ore and left in the stope.
4. Different grades of ore may be handled separately.
5. High percentage of extraction.
6. Very little caving or settling of the hanging wall.
7. Very flexible.

Disadvantages: 1. The most costly of all mining methods.
2. Production per man-shift is very low.
3. Rate of mining is slow.
4. A large amount of costly framed timber is used (about 20 board-feet per ton of ore removed).
5. Well trained workmen are necessary.
6. Very close supervision is required.
7. Use of mechanical equipment is limited.
8. Danger of mine fires because of the timber.
9. Stopes are difficult to ventilate.

Accident record: This method has the highest accident rate of any mining method, although its rate of fatal accidents is lower than that of some other methods. The high accident rate is caused in part by the large amount of timber that must be handled.

Cost per ton: The cost per ton for the square-set stoping varies more than that for any other method and for small mines will probably be $15 or more.

Square-set stoping is one of the more complicated methods of mining and should be directed only by experienced personnel.

PART III. — WHY MANY SMALL MINES PROVE UNPROFITABLE

There are many reasons why small mines prove unprofitable. The most common are as follows:

1. Lack of ore
2. Poor management
3. Lack of capital
4. Premature erection of a mill

The exploration program may be unsuccessful or may indicate only a small quantity of ore; when this ore has been mined out, the mine must be closed. There are also many instances where attempts have been made to mine material that was too low in grade to return the cost of production. Failures of this type are due primarily to poor management. It has been said that 90 per cent of the success of a venture depends upon management. This is true for mining as well as for any other kind of business. Good management may make a profit on low-grade ore, but poor management must have a bonanza mine to make a profit. It is advantageous for both the owner and the investor to see that the mine is well managed.

Many good small mines fail because there is not enough capital available for development, equipment, payroll, and supplies, whereby the mine might carry through the early stages to the period of profitable returns. Adequate financing should be assured before exploration or mining starts.

In many cases large sums of money are spent for the construction of a mill before exploration or development have been completed. The operators may then find insufficient ore to be treated in the mill, and that not enough capital is left to complete the mine development, or that the mill was not designed to treat the ore found. This situation results from inexperience or poor management.

There are many other reasons why small mines fail. Most of them result indirectly from poor management or lack of capital. The most common one is misunderstanding among those who are interested in the property. Other causes include excessive amount of water in the mine workings, changes in the market price of metals or minerals produced and disasters such as fires or caving.

PART IV — MILLS FOR SMALL MINES

Comparatively few small mines have sufficient ore reserves to justify the cost of erecting a mill for concentrating the ore. The amount of this reserve will depend upon the cost of custom milling or smelting plus the cost of transporting the raw ore as compared with the cost of concentration in a small mill plus the cost of transporting and smelting the concentrates. The reserves must be large enough so that the savings on their treatment will pay for the mill. The cost of operating a small mill is high, and frequently the recovery is lower than that for a larger mill. Labor costs alone will be a minimum of $3 per ton of ore treated, to which must be added the cost of supplies, power, repairs, taxes, and miscellaneous costs.

The operation of a concentrator requires substantial quantities of water, which must be assured before a decision is made to erect a concentrator.

Mills are expensive, and the simplest type of gravity concentration plant, including crushing and grinding, will cost $1,000 per ton of daily capacity, if good used equipment is used. Thus a mill of this type with a daily capacity of 25 tons will cost approximately $25,000. Using new equipment will add to the cost. If the mill is not located near a public utility power line, the cost of a power unit will be additional. A mill using selective flotation will cost substantially more than the gravity type, and a fine-grind cyanide plant will cost twice as much as a flotation mill.

A considerable knowledge of ore concentration is necessary to determine the proper flow sheet for the ore. Unless the operator is thoroughly trained in this field, he should obtain the services of a consulting metallurgist to test the ore and to design the mill properly. Such a man should be well and favorably known in his profession. A correctly designed mill may mean the difference between a profitable operation and failure.

In order to assist small operators, The Arizona Bureau of Mines provides an ore-testing service for ores originating within the State of Arizona. The charge for this work is nominal. Full details will be furnished upon request.

SERVICES OFFERED BY THE ARIZONA BUREAU OF MINES

(Continued from inside front cover)

3. Geologic investigations of mining districts and counties and the making of topographic and geologic maps and reports. In cooperation with the United States Geological Survey a large-scale base map, a reconnaissance geologic map, and a topographic map (100-meter contours) of the entire State have been published. Geologic reports on various mineral resources of the State are prepared.

4. The Bureau provides an ore-testing service for ores originating within the State of Arizona. Full details will be furnished on request.

5. Semitechnical meetings with miners and prospectors are held throughout the State.

6. The collection and dissemination of statistics relating to the mineral industries of the State.

7. The collecting and filing of all items relating to Arizona mines and minerals that appear in Arizona newspapers and in many technical periodicals.

MAPS OF ARIZONA

The Arizona Bureau of Mines now has available for distribution the following maps of the State:

A. Base map of Arizona on a scale of about 17 miles to the inch. This map is strictly geographic, indicating the positions of towns, railroads, rivers, surveyed lands, national forests, national parks and monuments, etc., revised to 1939. It is printed in black on one sheet 22x36 inches and sells for 30c unmounted.

C. Geologic map of Arizona in one sheet of many colors. It was issued in 1924 on the same scale as the topographic map, but it is now out of print, and its lithographic plates are worn beyond repair.

The Bureau is now prepared to supply sets of 44 kodachrome slides, 2x2 inches in size, covering the entire map. The slides may be used with either a low-cost pocket viewer or a projector. The price of the set is $9.00 which includes mailing charges.

D. Metallic Mineral Map of Arizona, 25x27 inches. This map consists of a red overprint made on Map A, and shows the principal known localities of metallic minerals by means of representative symbols. Roads are indicated. This map was revised in May, 1953, and sells for 30c when delivered without tube in the offices of the Bureau of Mines. If mailed, the cost, including mailing tube, is 45 cents.

E. Nonmetallic Mineral Map of Arizona, 25x27 inches, similar to Map D but devoted to nonmetallic minerals. This map sells for 30c when delivered without tube in the offices of the Bureau of Mines. If mailed, the cost including mailing tube, is 45 cents.

F. Map of Arizona Mining Districts, 25x27 inches. This map consists of a red overprint made on Map A and shows the principal mining districts of mining localities by means of numerals and index. Roads are also indicated. This map is sold for 30c when delivered without tube in the offices of the Bureau of Mines. If mailed the cost, including mailing tube is 45 cents.

All communications should be addressed and remittances made payable to the Arizona Bureau of Mines, University of Arizona, Tucson, Arizona.